# Characterization of Losses at the Distribution System

## Energy Distribution Cooperative – Cersul

Álvaro Coelho Bratti[*1], Oswaldo Hideo Ando Junior[2], João Mota Neto[3], Anderson Diogo Spacek[4], Vilson Luiz Coelho[5], André Abelardo Tavares[6], Mario Orlando Oliveira[7]

[*1,2,3,4,5,6]Department of Electrical Engineering, SATC Colegge

Criciúma/SC - Brazil

[7]Energy Study Center to Development (CEED), National University of Misiones –UNaM

Oberá, Misiones, Argentina.

[*1]alvarobratti@hotmail.com; [2]oswaldo.junior@satc.edu.br; [3]joao.neto@satc.edu.br; [4]anderson.spacek@satc.edu.br; [5]vilson.coelho@satc.edu.br; [6]andre.tavares@satc.edu.com; [7]oliveira@fio.unam.edu.ar

***Abstract***

This paper shows the importance of the control and the mitigation of technical and non-technical losses at electric energy distribution systems. For the classification and segmentation of such losses, the calculation methodology from the National Agency of Electric Energy (ANEEL) has been employed, presented at the seventh module of the Proceedings of Electric Energy Distribution at the National Electric System (PRODIST). As for the application of the exposed methodology, a case study was conducted on the distributor CERSUL, which had not developed a study about losses classification before. It was possible to identify the frailty of the methodology when applied to small systems or small size companies, since the results of the technical losses are different from the ones suggested by the bibliographical reference and the ones obtained during the measurements.

***Keywords***

*Technical Losses; Energy Distribution; Rural Electrification and Lessening.*

## Introduction

The losses are inevitable to the electric energy generation, transmission and distribution systems. Therefore, understanding its causes and stipulating mitigation actions in order to lessen the losses is a challenge to all the segments involved in the electrical sector.

Divided into technical and non-technical, the losses at the electrical sector are a hindrance to the development in Brazil. Data from the National Agency of Electric Energy (ANEEL, in Portuguese) emphasize that the non technical losses alone represent an annual cost of around R$ 5.5 billion which will rise to R$ 7 billion when the taxes not levied by the country are considered.

The losses that occur in the power systems are the major concern for both the distributor and the ANEEL. For the agency, and society in general, controlling the losses means more efficiency from the distributor, as well as the possibility to reduce the final cost of the electric energy. For the distributor, reducing losses results in an increase of the energy offering, apart from postponing the investments in the expansion of the system capacity.

## Theoretical Substantation

The electric power system has losses in its stages, as well as any other production process. The total amount of electric losses in all stages of the electric system is usually classified as global losses, whose generic representation is given by the sum of the technical and the non-technical losses (Queiroz, L. M. O., 2010; Kagan, N., Oliveira, C. C. B., and Robba, E. J., 2005; Coelho, J. S., 2010; Strauch, M. T., 2002).

The global losses calculated in a relatively simple form by subtracting the energy bought from the supplier from the energy to the consumers are billed. Therefore, the total amount of energy lost has been obtained, usually represented in percentage of the total bought energy. Since the supplier has a different billing cycle compared with the one the consumers have, its calculation is made for period of a year, aiming at the reduction of the possible associated error (Strauch, M. T., 2002).

*Technical Losses*

The technical losses are the energy dissipated in the stages of tension transformation and electric energy conduction between the supplier and the delivery point of the supplied consumer and distributor units, as well as at the measuring equipments. The technical losses are inherent to the system, and acknowledging its values is an important requirement to obtain the indices of the non-technical losses (Coelho, J. S., 2010; Méffe, A., 2001).

The technical losses cannot be eliminated, hence the attempts to reduce by means of studies on the grid to be optimized have been made (Queiroz, L. M. O., 2010; Oliveira, M. E., 2009).

Table 1 is presented below, showing the estimated data for the technical losses according to each segment (Méffe, A., 2001).

TABLE 1 AMOUNT OF LOSSES EXPECTED PER SEGMENT

| Segments | From the Total Energy (%) |
|---|---|
| Substation Transformer | 0.5 to 1.0 |
| Medium Voltage | 0.5 to 2.5 |
| Distribution Transformer | 1.0 to 2.0 |
| Low Voltage | 0.1 to 2.0 |
| Connecting Branches and Meters | 0.25 to 0.6 |
| Others | 0.2 to 0.8 |

*Non-Technical Losses*

The non-technical or commercial losses defined as the energy consumed or effectively delivered to the consumers, which was not billed by the distributors, are associated with the company management and caused by theft, fraud and errors during reading, billing and metering (Coelho, J. S., 2010; Strauch, M. T., 2002).

The amount of commercial losses cannot be directly calculated, but estimated and be obtained from the difference between the global and technical losses at the distributors. Thus, the more accurately the process calculates the technical losses, the more precise the value of non-technical losses is (Queiroz, L. M. O., 2010; Coelho, J. S., 2010; Strauch, M. T., 2002; Almeida, M. A. S., 2006).

Based on the analysis on the information from Fig. 1, it is possible to note that the percentage of lost energy in Brazil in the distribution segment reached 14.18% from the injected energy during 2006 and 2008, of which, 7.04% are related to the commercial losses of the distributors. This number varies a lot among the companies and the Brazilian regions. While some concessionaries show levels under 1 % in the south region, while other ones present indices above 30%, as in the north region of the country (ANEEL, 2009).

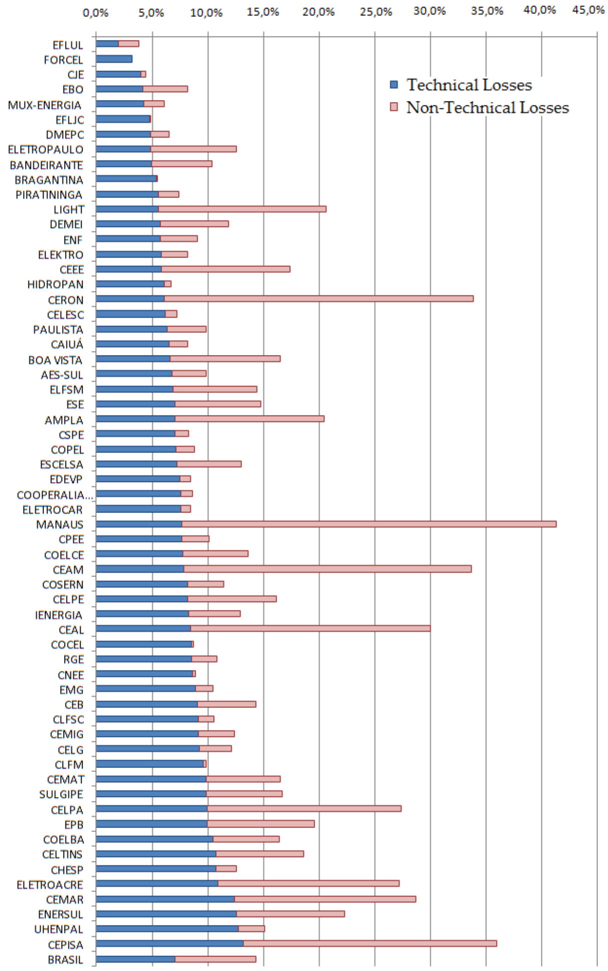



FIG. 1 ENERGY LOSSES AT THE DISTRIBUTION CONCESSIONARIES IN BRAZIL

The acceptable level of non-technical losses for each company, as well as the amount of money charged at the levies, has been defined by the ANEEL. These values are applied in each distribution area in different forms, as a way to guarantee that a fair amount is paid for the electric energy.

## Characterization of the Technical Losses

Aiming at a standardization of the information about the losses sent by the distributors, the ANEEL developed its own methodology to calculate the technical losses, which is described at the seventh module of the Proceedings of Electric Energy distribution at the National Electric System (PRODIST, in Portuguese). According to the agency, the application of such methodology has made possible the standardization of the distributors and has lessened the asymmetry in the sending of the information about

the technical losses, besides the non-technical ones (ANEEL, 2011).

To calculate the technical losses in the electric energy distribution, the ANEEL determines a division in segments as medium voltage grids, low voltage grids, transformers, connecting branches and meters. Besides that, in the end, the amount of 5% over the total technical losses should be added, due to the technical losses produced by corona effect, connections, capacitors, current transformers, power transformers, current leaks in isolators and lightning rods, supervisory systems and photoelectric relays. This simplification is due to the difficulty in calculation and measurement of such values, besides a lowermost value, if the amount of technical losses is taken into consideration (ANEEL, 2011).

While calculating energy losses, it is necessary to use daily loading curves, since the power losses in the segments are calculated with the use of the losses as for the average charge. Such curves enable the calculation of the losses coefficient, which, according to the ANEEL, is characterized with the average power loss divided by the power loss for the average demand. This calculation is represented by (1) (Oliveira, C. C. B., 2012).

$$CP = 1+\left(\frac{D_{PADRÃO}}{M}\right)^2 \qquad (1)$$

Where:

CP: Losses coefficient;

$D_{PADRÃO}$ [MVA]: Standard deviation of the daily load curve; and

M [MVA]: Average of the values obtained at the daily load curve.

However, the ANEEL allows that, if the distributor does not have the data to measure and calculate the losses coefficient, it is possible to use the values from the supplied distributor (ANEEL, 2011).

In this paper, only relevant items of each segment determined by the ANEEL will be presented. The formulae can be found at the seventh module of PRODIST (ANEEL, 2011).

***Medium Voltage***

The calculation to obtain the medium voltage losses is made considering the average demand and using the multiple linear regression system. To achieve it, the definition of the length for the trunk conductor and branch is necessary (ANEEL, 2011).

Then, the trunk conductor is "the feeder part that leaves the substation until its closest point where the highest current downstream is lower or equal to the highest current of any branch upstream". Also, the branch conductors are all the parts that do not fit in the description above. The trunk conductor will not be bigger than 90% of the whole feeder, for purposes of calculation (ANEEL, 2011).

Fig. 2 exemplifies the definition of trunk and branch conductors. In the image, the parts 1, 2 and 3 are classified as trunk, and the others are branches (Oliveira, C. C. B., 2012).

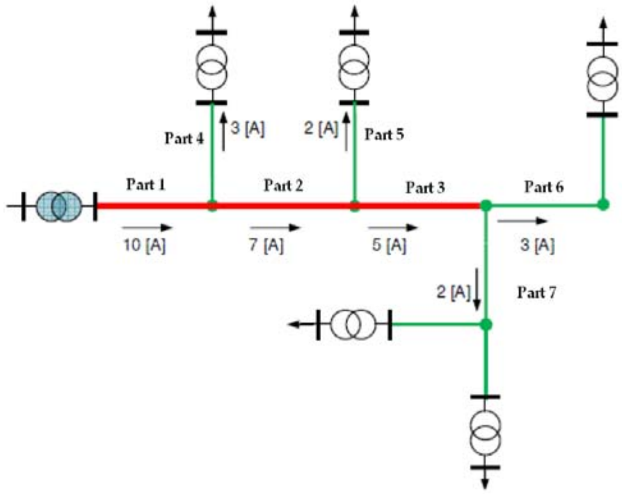



FIG. 2 EXAMPLE OF THE DEFINITION OF TRUNK AND BRANCH CONDUCTORS

***Transformers***

In the transformers, according to the ANEEL, the values used to calculate the power losses in charged and idle transformers should be the ones included in the NBR 5440/2011 (ANEEL, 2011).

***Low Voltage***

For such losses, the ANEEL defines five different typologies for grid classification. The distributors should choose which method to be used. The first method is according to Table 2, where $L_{CIRC}$ represents the secondary circuit total extension. While the second method goes according to the similarities of the circuit and the typologies in Fig. 3. Both methods define the amount of elementary parts for the calculation of low voltage losses (ANEEL, 2011).

For making the calculations, the definition of the secondary grid trunk and branch is necessary. The trunk is defined as the conductor with the lowest resistance in ohms by kilometer among the conductors of the analyzed circuit, while the branch is the second

lowest resistance (ANEEL, 2011).

TABLE 2 LOW VOLTAGE GRIDS TYPOLOGIES

| Typology | Elementary Parts | Extension |
|---|---|---|
| 1 | 2 | $L_{CIRC} \leq 100$ |
| 2 | 4 | $100 < L_{CIRC} \leq 200$ |
| 3 | 8 | $200 < L_{CIRC} \leq 350$ |
| 4 | 16 | $350 < L_{CIRC} \leq 500$ |
| 5 | 32 | $L_{CIRC} > 500$ |

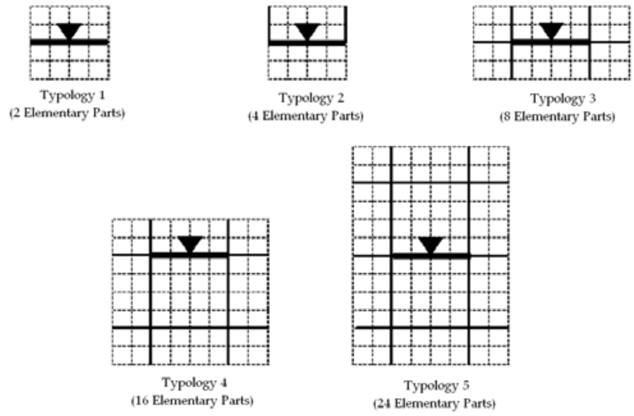



FIG. 3 GRID TYPOLOGIES ACCORDING TO ELEMENTARY PARTS

In the low voltage losses, the ANEEL determines the addition of 15% to the total calculated losses, due to the charge disequilibrium and the asymmetrical positioning of the transformer (ANEEL, 2011).

### *Connecting Branches and Meters*

The losses in the connecting branches of the consumers are calculated based on the average demand.

For the meters, the ANEEL defines the power losses according to the tension coil, that is, 1 W of circuit losses in the electromechanical meters and 0.5 W per circuit in the electronic meters (ANEEL, 2011).

## The Study Case of CERSUL

The Energy Distribution Cooperative (CERSUL, in Portuguese) has currently around 2200 kilometers of electric energy distribution grids, between medium voltage, in the class of 15 kV, and low voltage, with the available voltages of 440 V, 380 V and 220 V. The company system has more than 2000 installed transformers which provide energy directly to a great part of the 16 thousand company consumer unities.

In this case study, two feeders among the seven that the company possesses have been used: the TVO-05 and the MJA-02, due to the information availability and the measuring possibility, using energy analyzers, compared with the calculated losses.

The TVO-05 is an express feeder, with 22 kilometers of medium voltage, which supplies only one client from the subgroup A4. On the other hand, the MJA-02 is a relatively short feeder, with around 17 kilometers of medium voltage, which supplies approximately 200 consumer unities both from the subgroup A4 and the group B.

For the purposes of losses calculation, the period from May 2011 to May 2012 was used, aiming at the reduction of the difference between the cycles of energy billing of the energy bought and the one sold by the distributor. It is important to highlight that all equations are described at the seventh module of the PRODIST.

Table 3 was created with the data given by the distributor CERSUL concerning the total energy losses for both supplying points, in one year period from May 2011 to 2012.

TABLE 3 ENERGY LOSSES DATA FOR THE SUPPLYING POINTS

| Supplying | Acquired Energy [MWh/ year] | Offered Energy [MWh/ year] | Total Energy Losses [MWh/ year] | Total Losses |
|---|---|---|---|---|
| SE TVO | 130374.037 | 119273.87 | 11100.176 | 8.51% |
| SE MJA | 3599.109 | 3405.961 | 193.148 | 5.37% |

The values of the losses coefficient used by the supplier distributor Electrical Centrals of Santa Catarina S.A. – CELESC are described in the Technical Note 0053/2012-SRD/ANEEL and represented in Table 4 below, due to the fact that the CERSUL does not possess meter data for the characterization of the daily average load curves (ANEEL, 2011).

TABLE 4 CELESC LOSSES COEFFICIENTS

| Segment | Losses Coefficient |
|---|---|
| Substation Transformers | 1.06 |
| Medium Voltage | 1.1 |
| Distributor Transformers | 1.2 |
| Low Voltage | 1.5 |
| Connecting Branch | 1.5 |
| Meters | 1.5 |

### *Medium Voltage Losses*

Considering the data given by the distributor CERSUL and Table 4, the power and energy losses for both feeders were calculated.

With the obtained values, it was possible to calculate the percentage of medium voltage losses regarding the

acquired energy in each feeder. For the feeder TVO 05, the losses were 2.33 %, and for the MJA 02, 0.40%.

### *Transformers Losses*

Besides the usual transformers losses, the losses at the CERSUL increased after the installation of meters in use of the Power Line Communications system – PLC, which resulted in more technical losses at the transformers, since the consumer unities where they were installed are seasonal irrigation bombs and, in most cases, they possess exclusive transformers, which work poorly during the months when the consumers are off. Before the installation of the PLC, these transformers were turned off with the other consumer unities. Even so, this system has caused the decrease of management expenses, since it provides the cut and restart from a distance, as well as the identification of energy lacking and the remote reading acquisition. It has also made possible to identify the theft of transformers.

Considering the data in Table 4 and the information given by the distributor CERSUL, the transformers losses from the Feeder MJA 02 were calculated. The transformers losses result was 0.99% from the total acquired energy in the feeder.

Besides the distributor transformers losses, CERSUL has losses at the Substation – SE transformers, where the voltage is reduced from 69 kV to 13.8 kV.

From Table 4, the SE transformers losses were calculated according to the data given by the distributor CERSUL. The energy losses were 0.455% from the total SE TVO consumption.

### *Low Voltage Losses*

Considering Tables 2 and 4, and the data given by the distributor CERSUL, the low voltage losses from the feeder MJA 02 were calculated. The resulting energy losses regarding this feeder were 0.051%. However, according to the ANEEL determination, the charge unbalancing of the low voltage circuit must be considered, so the value of 15% of the losses should be added. Thus it is obtained 0.059% of low voltage energy losses in the feeder.

### *Connecting Branches and Meters Losses*

By means of the Table 4 and the data given by the distributor CERSUL, it was possible to calculate the losses in the connecting branches and meters of the Feeder MJA 02. The resulting losses regarding the acquired energy were 0.074%.

As well as the transformer losses, the PLC system increased the meter losses, since there is a data transmitter module installed with the meter, which presents an energy dissipation of 2 W. The meters with PLC represent around 7% from the total meters.

### *Other Losses*

Overall, the values calculated for each segment have resulted in 1.53% of the technical losses in the feeder MJA 02. However, according to the ANEEL, once this value is found, 5% should be added, referring to other segments. Therefore, the technical losses result in 1.6% of the energy losses in the feeder MJA 02.

### *Non-Technical Losses*

Once the values for technical losses are obtained, and using the Table 3, which presents 5.37% for the total losses of the feeder, it is possible to estimate the value of the non-technical losses, by subtracting the technical losses from the total losses. Table 5 is created to show these values.

TABLE 5 VALUES OF THE ENERGY LOSSES IN THE FEEDER MJA 02

| **Total Losses** | **Technical Losses** | **Non-Technical Losses** |
|---|---|---|
| 5.37% | 1.60% | 3.77% |

## Results Analysis and Discussion

With all the obtained results, Table 6 is presented in order to show the calculated losses compared with the data from Table 1.

TABLE 6 RESULTING LOSSES IN THE FEEDER MJA 02

| **Segments** | **Value** |
|---|---|
| Total losses | 5.37% |
| Medium voltage | 0.40% |
| Transformers | 0.99% |
| Low voltage | 0.059% |
| Branches and meters | 0.074% |
| Other | 0.0763% |
| Total of technical losses | 1.60% |
| Non-technical losses | 3.77% |

Analyzing the data from Table 6, it is possible to notice the value of 1.6% for the technical losses and 3.77% for the non-technical ones. As for comparison, the losses values from the Alliance Cooperative (COOPERALIANÇA, in Portuguese) were extracted from Figure 1, which presents losses per Brazilian concessionaries. That Cooperative is a distributor in the south of Santa Catarina, whose technical losses values are around 8% and the non-technical ones around 1%. Considering the Technical Note 298/2011

from the ANEEL, the CERSUL should be in the same cluster as the distributor COPERALIANÇA, that is, the same similarity group, since there is a similar socioeconomic complexity in the concession area and about the same number of consumers they supply (ANEEL, 2011).

In that comparison, it was found that the discovered values of the losses, using the methodology from the ANEEL, for the Feeder MJA 02 from the distributor CERSUL, do not match the ones from the cluster distributor. Also, the obtained values for the energy losses percentage fail to present the results proposed by the reference in the Table 1.

Neto states that the methodology from the ANEEL, if applied to small feeder or small size substations, can lead to errors in the calculation of the technical losses, since it uses typical grid data, medium power factor, standard cable coils and other parameters that, when analyzed in small proportions, do not represent the reality (Neto, E. A. C. A, 2012).

As an attempt has been made to confirm that the methodology from the ANEEL is not appropriate for small systems, measurements at the medium voltage grid of the feeder TVO 05, in which two energy analyzers were installed: one in the output of the feeder SE TVO (source) and the other in the consumption point (load).

Using the power data obtained in the measurements, the losses coefficient from Table 4 and the other data given by the distributor CERSUL, the medium voltage losses in the feeder TVO 05 were calculated again, based on the ANEEL methodology. From those calculations, the index of 1.3% of energy losses was obtained from the total energy supplied by the feeder.

From the measurements in the analysers, it was possible to obtain the energy values measured in the source and in the load. After that, the losses calculation was made based on the difference from the analyzers measurements. The measured index of technical energy losses was 2.34%. Finally, it is clear to see the difference between the measured value of the technical losses and the one calculated through the methodology from the ANEEL. The losses calculated using the methodology from ANEEL represent only 55% from the real value of the losses in the feeder TVO 05.

With the difference between the calculation and the measurements in the feeder, it is concluded that the values for the technical and non-technical losses in Table 5 fail to represent the reality for the feeder MJA 02 either. Such reasoning is justified by the fact that the MJA 02 is a small size feeder as well as the TVO 05, besides that both have been analyzed individually.

## Conclusions

Controlling and mitigating the losses in the Brazilian electric energy distributions systems are of major importance for the three involved agents: government, distributors and clients. For them, the smaller the level of losses is, the better the tax affordability and profits, and the smaller the value of the energy bill are, respectively.

It is noticeable that the global losses for the distributor CERSUL are under the national average. However, it is important to highlight that their permission area is of low socioeconomic complexity, which tends to show low non-technical losses indices.

The case study has contributed to the indication on the deficiency in the calculation methodology from ANEEL when applied to small size systems. That is due to the fact that the methodology uses typical grid data, medium power factor, standard conductors and other parameters that, when analyzed in small circuits, lead to wrong losses values. Therefore, it is noted that the small companies will have to propose a different calculation methodology to the ANEEL, so that it reflects the reality of their energy distribution systems, since the agency, in the seventh module of the PRODIST, allows the use of other calculation methodology only if validated.

Although the methodology from the agency has failed to present the expected results, the CERSUL and all other distributors will have to send the losses information, according to the methodology, in the tax revision cycles. Thus, this study is helpful for those distributors on better understanding the use of such methodology and calculating the losses for their electric energy systems.

## REFERENCES

Almeida, M. A. S. de. Metodologia de identificação de perdas não técnicas em unidades consumidoras por atividade de consumo. 2006. 105 f. Dissertation (Master in Electrical Engineering). University UNIFACS Salvador. Salvador, 2006.

ANEEL, National Agency of Electricity. Bank Information

Generation. Report, 2009.

ANEEL, National Agency of Electricity. Determination of distribution losses for the 3rd Cycle of Periodic Tariff Review CELESC Distribution S / A - CELESC-DIS. Technical Note 0053/2012-SRD/ANEEL, ANEEL, 2011.

ANEEL, National Agency of Electricity. Methodology regulatory treatment for non-technical losses of electricity for the third cycle of periodic review of distribution utilities electricity. Technical Note No. 298, ANEEL, 2011.

ANEEL, National Agency of Electricity. Procedures for Electric Power Distribution System National Electrical - PRODIST, Module 7, ANEEL, 2011.

Coelho, J. S. Tratamento regulatório de perdas não técnicas. 3ª Conferência da Associação de Reguladores de Energia dos Países de Língua Oficial Portuguesa – RELOP. 2010, Rio de Janeiro.

Kagan, N; Oliveira, C. C. B de; Robba, E. J. Introdução aos Sistemas de Distribuição de Energia Elétrica. São Paulo: Edgard Blucher, 2005.

Méffe, A. Metodologia para Cálculo de Perdas Técnicas Por Segmento do Sistema de Distribuição. 2001. 139 f. Dissertation (Master in Electrical Engineering). Polytechnic School of the University of São Paulo. São Paulo, 2001.

Neto, E. A. C. A. Metodologia probabilística para estimação de perdas técnicas e comerciais em alimentadores de sistema de distribuição. 2012. 208 f. Thesis (Ph.D. in Electrical Engineering). Federal University of Santa Catarina. Florianópolis, 2012.

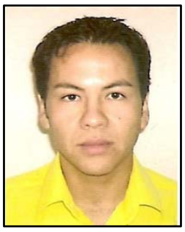
Oliveira, C. C. B. de. Perdas técnicas e não técnicas – aspectos regulatórios. 2ª Seminário sobre perdas em sistema de distribuição de energia elétrica. 2012, Curitiba.

Oliveira, M. E. Avaliação de metodologias de cálculo de perdas técnicas em sistemas de distribuição de energia elétrica. 2009. 137 f. Thesis (Ph.D. in Electrical Engineering). Universidade Estadual Paulista UNESP. Ilha Solteira, 2009.

Queiroz, L. M. O. de. Estimação e análise das perdas técnicas na distribuição de energia elétrica. 2010. 155 f. Thesis (Ph.D. in Electrical Engineering) - University of Campinas. Campinas, 2010.

Strauch, M. T. Desenvolvimento de metodologia para cálculo de perdas elétricas em redes de distribuição de baixa tensão. 2002. 104 f. Dissertation (Master in Electrical Engineering). Universidade Salvador - UNIFACS. Salvador, 2002.

**Álvaro Coelho Bratti**, undergraduate on the eleventh semester of the course in Electric Engineering at SATC College (Brazil), and project analyst at the Energy Distribution Cooperative – CERSUL



**Oswaldo Hideo Ando Junior** majored in Electrical Engineering and specialization in Business Management from the Lutheran University of Brazil - ULBRA with a Masters in Electrical Engineering at the Federal University of Rio Grande do Sul – UFRGS. Currently, he is lecturer of Electrical Engineering, Faculty SATC. Reviewer ad hoc FAPESC and PMAPS. His work interests are mainly in the areas: Energy Conversion, Power Quality and Power Systems..

**João Mota Neto** graduated in Industrial Automation Technology at the University of Southern Santa Catarina and received master's degree in mechanical engineering- UFRGS. Currently, he is lecturer of electrical engineering and industrial automation technology in the Faculty SATC Developing research in the areas of energy efficiency, instrumentation and automation.

**Anderson Diogo Spacek** majored in Industrial Automation Technology at the University of Southern Santa Catarina and master's degree in engineering (PPGE3M/UFRGS) Currently, he is lecturer of electrical engineering and industrial automation technology in the Faculty SATC Developing research in the areas of energy efficiency and automation.

**Vilson Luiz Coelho** Bachelor's at Electric Engineering from UFSC (1979), master's at Electric Engineering from UFSC (2005) and Ph.D. Electric Engineering from UFSC (2010). He is currently post doctoral of University of São Paulo and professor at Engineering School SATC. He has experience in Electric Engineering, focusing on Power Transmission and Distribution Lines,

acting on the following subjects: Protection, Lightning, Surge Arresters and Insulation Level.

**André Aberlado Tavares** PhD in Electrical Engineering (in course) from the Federal University of Santa Catarina, experience as an electrical engineer in the field of electrical projects, transmission lines, substations, power plants and hydro power plants. Currently coordinating the course of Electrical Engineering Faculty of SATC.

**Mario Orlando Oliveira** (M'09) was born in Capiovi, Misiones, Argentina, on May 13, 1979. He received the Eletromechanical Engineering degree from the National University of Misiones (UNaM), Argentina, in 2005 and M.Eng. degree from the Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, in 2009. Currently, he is researcher of the Energy Study Center to Development (CEED) and auxiliary professor of the UNaM. His research interests include electrical machines protection and modeling, faults detection and location.